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Attenuation properties of health protection accessories during mobile phone exposure on the human head phantom

***Abstract**. The aim of the study was to measure and evaluate the attenuation of the electromagnetic field using personal protective textile accessories within three frequencies: 825 MHz, 1760 MHz and 2109 MHz. Measurements on the human head phantom were performed 1. without a protective accessory, 2. with the protective cap containing the silver fibres, 3. with the visor cap containing the silver fibres, 4. with an ordinary aluminium foil, 5. with the classic cap and 6. with the visor cap without any protective elements. The best shielding effectiveness was provided by the protective cap containing a silver, which covered almost the entire area of the head. It provided the highest attenuation for all frequencies, considering the average from each side (left, right, top of the head): 10.85 ± 1.44 dB (825 MHz), 14.55 ± 4.30 dB (1760 MHz) and 12.45 ± 4.88 dB (2109 MHz). The highest value for particular side of the head was observed for the visor cap containing a silver 19.25 ± 6.95 dB for the top of the head (1760 MHz). For the classic caps, the attenuation was lower than 1dB.*

Streszczenie.** Celem pracy był pomiar i ocena tłumienia pola elektromagnetycznego za pomocą tekstylnych akcesoriów ochrony osobistej w zakresie trzech częstotliwości: 825 MHz, 1760 MHz i 2109 MHz. Pomiary na fantomie głowy ludzkiej wykonano 1. bez akcesorium ochronnego, 2. z nakładką ochronną zawierającą włókna srebrne, 3. z nakładką przyłbicy zawierającą włókna srebrne, 4. ze zwykłą folią aluminiową, 5. z klasyczną i 6. z nakładką z daszkiem bez żadnych elementów ochronnych. Najlepszą skuteczność ekranowania zapewniała nasadka ochronna zawierająca srebro, która pokrywała niemal całą powierzchnię głowy. Zapewniał najwyższe tłumienie dla wszystkich częstotliwości, biorąc pod uwagę średnią z każdej strony (lewa, prawa, czubek głowy): 10,85 ± 1,44 dB (825 MHz), 14,55 ± 4,30 dB (1760 MHz) i 12,45 ± 4,88 dB (2109 MHz). Najwyższą wartość dla poszczególnych stron głowy zaobserwowano dla nasadki przyłbicy zawierającej srebro 19,25 ± 6,95 dB dla czubka głowy (1760 MHz). Dla klasycznych czapek tłumienie było mniejsze niż 1dB.* (Właściwości tłumiące akcesoriów ochrony zdrowia podczas ekspozycji telefonu komórkowego na fantom głowy człowieka***)

Keywords: electromagnetic field exposure, mobile phone, personal protective accessories, electromagnetic hypersensitivity.
Słowa kluczowe: pole elektromagnetyczne, .telefon komórkowy, tłumienie pola

Introduction

With the extensive increase in technological devices (mobile phones, tablets, Wi-Fi routers and new 5G technologies), the number of people with health problems attributed to the syndrome of electromagnetic (EM) hypersensitivity is also increasing proportionally. It is already known that exposure to the electromagnetic field (EMF) can lead to the harmful biological effects [1, 2, 3, 4]. These effects depend on the physical parameters such as the frequency (depth of penetration), the distance from the source, the intensity, the duration, the polarization, the signal modulation [5], and also living and working environment [6, 7, 8, 9, 10]. The non-thermal EMF effects may interfere with the function of the cardiovascular, the nervous and the endocrine systems, and the excretory mechanism. According to the published study [11], the long-term EMF exposure produced by a cell phone (900 – 1800 MHz) increased the liability for hypertension reflected on the electrocardiogram and the cardiac weights which was accompanied by the histopathological changes in the myocardium. Our previous study [12] revealed significantly increased parasympathetic nerve activity after the short-term exposure of the head area to the radiofrequency (RF) EMF, when passing the ortho-clinostatic test. Study group Hardell et al. [13] informed that the use of the mobile phone may be a risk factor for the central nervous system lymphoma.

The action of EMF on the stem cells can also disrupt brain development in young children, which can lead to autism [14]. Reiser et al. [15] reported that primarily affected was the brain due to the proximity of a phone during a call, in comparison to the Wi-Fi devices or the Base Transceiver Stations where whole-body exposure occurs. The mobile telecommunication networks such as WiFi, Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS) or Long Term Evolution (LTE), operate on a digital pulse transmission, making them more biologically active [16]. Other study group [17] informed that people who used a cell phone daily more than 50 minutes are predisposed to early dementia or thermal damage due to burning glucose in the brain.

There are also studies that have not confirmed the detrimental effects of EMF. E.g. in the study by Sommer et al. [18], no adverse effects on fertility and development of mice during long-term UMTS signal exposure have been demonstrated, and also any adverse effects on pregnancy or development of rats [19]. According to Klose et al. [20], prolonged exposure to RF EMF has no effect on learning and behaviour of rats. The opinions on RF EMFs are still ambiguous. However, in 2011, exposure to RF EMF has been classified as a possible cancer agent (group 2B) both by ICNIRP and WHO [21]. EMF exposure is significantly able to disrupt the functions of the neurons and the other cells in the body during the exposure to a telecommunication signal in the shielded areas of the garages, the reinforced concrete buildings, the trains, etc. Therefore, any paper that deals with the physical properties and the biological effects of RF EMF can make a significant contribution to the protection of the living organisms, including the animals and the humans.

EMF shielding devices and the shielding materials are designed to protect the health. E.g. conductive polymers (such as polyacetylene, polypyrrole, polyaniline) may be directly applied in the textile materials [22]. They are considered to be a multilayer system of the shielding materials formed from metal inclusions like aluminium, copper, silver and nickel particles mixed in a polymer/plastic medium [23].

Some protective accessories are commercially available so certain people used them in their daily lives while trusting their effects. Thus, the aim of this study was to measure the attenuations of protective accessories using the human head phantom during the exposure to RF EMF in the real conditions.

Material and methods
Phantom

The phantom models are used to analyse exposure without the presence of a human object. In this study, the homogeneous phantom of the human head was used. The detailed information was presented elsewhere [24]. Of note, this model represents 3D scan of the real person composed of the two most important tissues forming the human head: bone-like and brain-like tissue. The shell of the phantom was composed of the 44.4% Aluminium, 5% Carbon and 50.6% ABS-polyurethane with the 5 mm thickness, which corresponds to the average thickness of a human adult skull. In the upper part, there is located a 5 cm hole for filling the phantom with solution (brain-like tissue). This solution contains: 12.76 g of cellulose, 2.288 dm^3 of water, 2.744 kg of sugar and 4.94 g of preventol biocide with the total volume in the head 4 dm^3. The relative permittivity and electrical conductivity correspond to the average values of a bone and an intracranial tissue (brain and cerebrospinal fluid) with dielectric properties of the mixed solution (20°C, 1800 MHz): ε_r = 41.0 and σ = 0.85 S/m [24].

Exposure system

GSM/DCS/PCS 900/1800/1900 MHz (Yageo, Taiwan) was opted as transmitting (source) antenna attached on the wooden stand. It is able to work within the frequency ranges GSM 900 with a maximum gain of 0-0.5 dBi, DCS 1800 and PCS 1900, with a maximum gain of 0.5-1 dBi with a linear polarization. Size of the antenna was 35x6x0.4 mm.

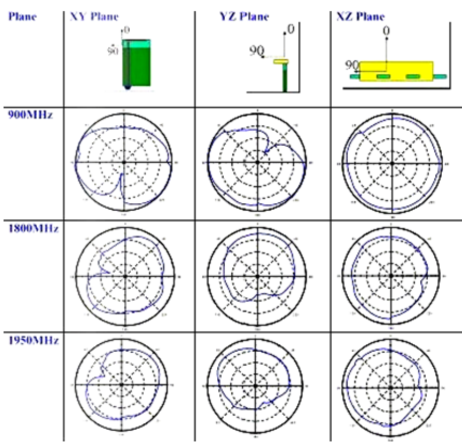


Fig.1. Radiation diagrams of the transmitting antenna.

The transmitting antenna was connected to EMF exposure system consisting of the signal generator Agilent Technologies N9310A (USA) and the 5 W Research Amplifier 5S1G4 (USA) where the output power was set to 2 W. Receiving multi-band antenna ANT-GSMQB (RF Solutions, UK) was immersed in the fluid inside the phantom and connected to the EMF spectrum analyser NARDA SRM-3006 (Germany). The receiving antenna was suitable to operate within the frequency ranges 824-960 MHz, 1710-1990 MHz and 1900-2200 MHz with a maximum gain of +3 dBi. The design of the RF exposure system is shown in Fig. 2.

The radiating power was measured over 6-minute intervals according to Decree 534/2007 of Slovak Republic [25] and ICNIRP [26] guidelines. Measurements were performed at three frequencies: 825 MHz (corresponding to the GSM800 standard), 1760 MHz (DCS1800 and GSM1800 standard, respectively) and 2109 MHz (UMTS2100 standard).

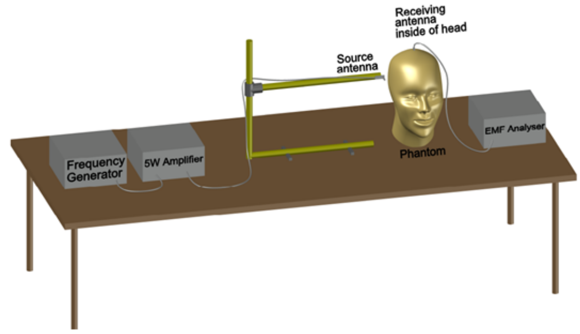


Fig.2. RF exposure system design.

Accessories

The protective cap containing silver (AGC) was a Beanie type cap made by SHIELD signalproof apparel. It was made of the outer layer (35% cotton, 45% polyester, and 20% spandex) and the inner layer 120 μm thick (90% silver fibre and 10% spandex). The visor cap containing silver (AGV) was a baseball type cap made by SHIELD signalproof apparel. The outer layer was made of 100% acrylic and the inner 90% silver fibre, 10% spandex with the same thickness of 120 μm. AGC and AGV did not contain other metal parts except the silver fibres. To determine the shielding function of the textile material, two more caps were involved into the measurements for comparison: the classic cap (CC) made of 70% polyester, 28% cotton and 2% elastane and the classic visor cap (CV) made of 100% polyester. In addition, these classic caps contained the metal parts (snaps) on the top, back or on the sides. Excessive EMF protection was simulated by a 10 μm thick homogeneous aluminium foil (ALF), which was formed in the shape of the cap.

Fig.3. Human head phantom WP (A), with AGC (B) and with AGV (C).

Measurement protocol

At the beginning, the exposure measurements were performed on the phantom without any protection (WP) for each frequency (825 MHz, 1760 MHz, 2109 MHz). These values served as the reference values for comparison with the protective accessories and the classic caps. Three sides of the head were measured for each protective accessory: the right side, the left side and the top of the head.

The 9 points on each side were selected in order to obtain an average value for the particular side. The distance between the antenna and the phantom was set to 5 cm what corresponds to a near-field EMF representing the real conditions of a cell phone usage. The positioning system consisted of a wooden stand with a sliding arm which was able to fix the transmitting antenna along the y-axis in the three levels: 25 cm (points 1-3), 21 cm (points 4-6) and 17 cm (points 7-9) from the table level.

To evaluate the effectiveness of the protective accessories, the measurements were taken between WP, 4 caps and ALF for all three sides of the head (9 points for each side) and for each of the 3 frequencies. Thus, totally 162 values were obtained.

Simulations

The exposure setup was numerically simulated in CST Studio Suite. The male phantom Gustav (CST Voxel Family) with a resolution of 2.08×2.08×2.0 mm was used to provide a comprehensive information about SAR (Specific absorption rate) distribution inside of the human head (Fig.4.). The antenna had the same parameters as the transmitting antenna used in the exposure setup placed 5 cm from the phantom.

Statistics

Statistical significance was determined using MS Office Excel. The p values were calculated by Student's paired t-test and only $p<0.05$ were considered as significant.

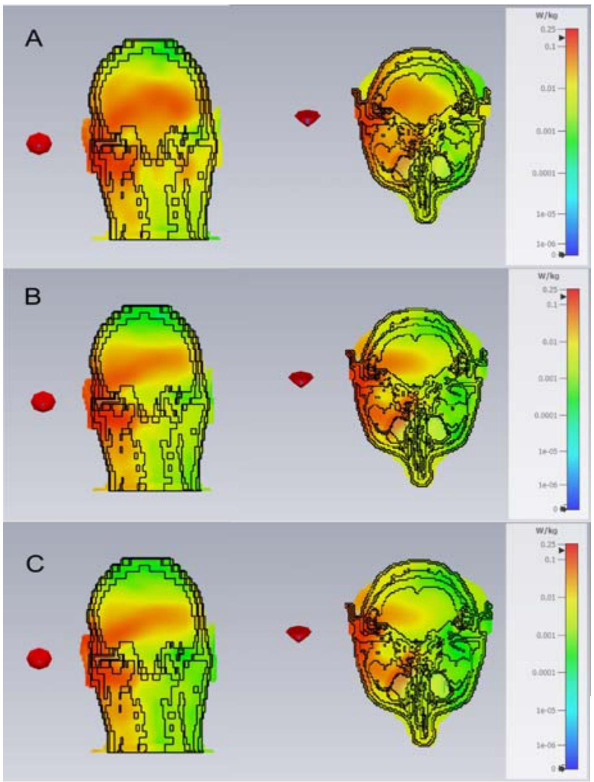


Fig.4. Numerical simulation showing SAR_{10} spatial distribution at the head cross-section in the vertical direction and horizontal direction for the frequency 825 MHz (A), 1760 MHz (B) and 2109 MHz (C).

Results

The results from the simulations showed the maximum SAR value for 10 g of tissue for 825 MHz 0.1541 W/kg, for 1760 MHz 0.1536 W/kg and for 2109 MHz the value reached 0.1342 W/kg.

The results in the Table 1. and in Fig. 5. are given in the form of the attenuation in (dB) calculated according the formula (1).

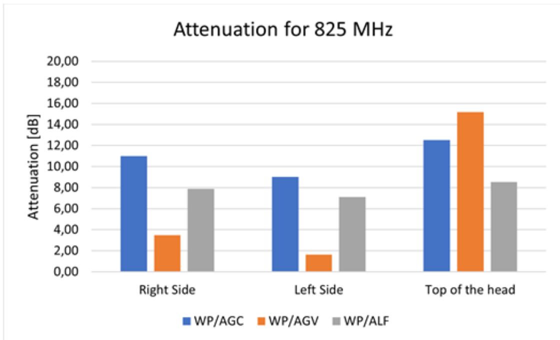
$$attenuation = 10 \log_{10} \frac{P_1}{P_2} \quad (1)$$

where: P_1 represents "unshielded" power and P_2 represents "shielded" power.

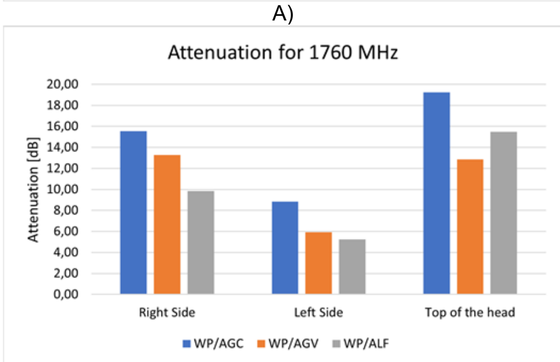
Table 1. Attenuation of specific protective accessories and classic caps.

Attenuation [dB]	Right side	Left side	Top of the head
Frequency 825 MHz			
WP/AGC	11.00 ± 2.54	9.02 ± 4.34	12.53 ± 8.75
WP/AGV	3.47 ± 2.01	1.65 ± 2.61	15.16 ± 7.32
WP/CC	1.69 ± 1.18	< 1.00	< 1.00
WP/CV	< 1.00	< 1.00	< 1.00
WP/ALF	7.88 ± 2.02	7.11 ± 2.74	8.53 ± 7.53
Frequency 1760 MHz			
WP/AGC	15.54 ± 2.73	8.85 ± 4.43	19.25 ± 6.95
WP/AGV	13.27 ± 3.36	5.93 ± 5.35	12.87 ± 8.56
WP/CC	< 1.00	< 1.00	< 1.00
WP/CV	< 1.00	< 1.00	< 1.00
WP/ALF	9.84 ± 4.46	5.24 ± 4.86	15.47 ± 8.35
Frequency 2109 MHz			
WP/AGC	14.81 ± 6.61	5.65 ± 5.83	16.89 ± 8.15
WP/AGV	13.11 ± 5.47	4.25 ± 5.02	11.97 ± 8.18
WP/CC	< 1.00	< 1.00	< 1.00
WP/CV	< 1.00	< 1.00	< 1.00
WP/ALF	11.21 ± 7.00	4.84 ± 4.90	11.54 ± 8.00

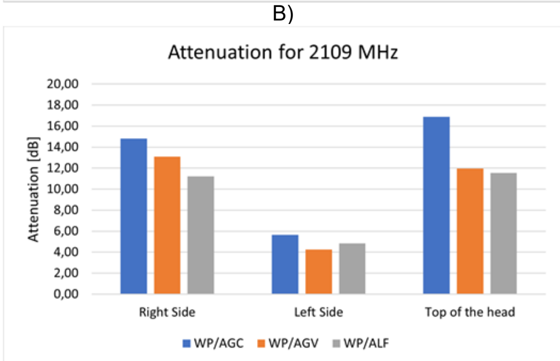
WP—without protection, AGC—Ag cap, AGV—Ag visor cap, CC—classic cap, CV—classic visor cap, ALF—Al foil



A)



B)



C)

Fig.5. The effectiveness of the attenuation accessories for each side of the head and for frequency A) 825 MHz, B) 1760 MHz, C) 2109 MHz.

While the phantom was built according to the real person, it does not have the identical sides. Therefore, there is no equal attenuation for the right and left sides of the head. The highest value of attenuation was observed for WP vs. AGV for frequency 825 MHz (15.16 ± 7.32 dB) at the top of the head. In the case of 1760 MHz the highest attenuation was noticed for WP vs. AGC (19.25 ± 6.95 dB) and for 2109 MHz, the highest value of attenuation was for WP vs. AGC (16.89 ± 8.15 dB). The attenuations below 1 dB were not considered significant. It occurred in the classic cap and the classic visor cap.

The highest average attenuation from all sides of the head for 825 MHz had AGC (10.85 ± 1.44 dB), ALF (7.84 ± 0.58 dB) and AGV (6.76 ± 5.99 dB) respectively. For frequency 1760 MHz, the highest average attenuation was for AGC (14.55 ± 4.30 dB), AGV (10.69 ± 3.37 dB) and ALF (10.18 ± 4.18 dB). Similar situation was observed for 2109 MHz, where the highest values had AGC (12.45 ± 4.88 dB), AGV (9.78 ± 3.94 dB), ALF (9.20 ± 3.08 dB) respectively.

Table 2. provides the statistical significance of the different combinations of the protective accessories, classic caps and aluminium foil for the given sides of the head and frequency.

Table 2. Statistical significance of the protective accessories and classic caps for the given sides of the head and for each frequency.

	Right side	Left side	Top of the head
Frequency 825 MHz			
AGC/WP	***	***	**
CC/WP	**	ns	ns
AGC/ALF	*	ns	***
AGV/WP	**	ns	***
CV/WP	**	ns	ns
ALF/AGV	**	***	***
ALF/WP	***	***	*
Frequency 1760 MHz			
AGC/WP	***	***	***
CC/WP	ns	ns	ns
AGC/ALF	**	**	*
AGV/WP	***	*	**
CV/WP	ns	ns	ns
ALF/AGV	*	ns	*
ALF/WP	***	*	***
Frequency 2109 MHz			
AGC/WP	***	*	***
CC/WP	ns	ns	ns
AGC/ALF	*	ns	*
AGV/WP	***	*	**
CV/WP	ns	ns	ns
ALF/AGV	ns	ns	ns
ALF/WP	**	*	**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, ns – not significant
WP—without protection, AGC—Ag cap, AGV—Ag visor cap, CC—classic cap, CV—classic visor cap, ALF—Al foil

Discussion

The aim of this study was to evaluate the effect of protective accessories against RF EMF exposure. Different shape of the particular protective accessory was able to cover differed head area. In the case of AGC, the protective material covered also the ear part and thus provided the most effective protective accessory for each frequency. However, AGV had the better shielding properties in the upper part of the head for 825 MHz frequency. Interesting was, that the pure homogeneous ALF had the lower shielding effectiveness comparing to AGC containing the silver. The silver is even better conductor, but in the caps, it is embedded in the form of the fibres. In simulation study by Januszkiewicz [27], the tinfoil head cover reduced the power density by half for the side area (750 MHz). In another study [28], a grid piece made of galvanized iron was used as a metal shielding with the attenuation effectiveness 80% during the exposure to 1950 MHz at 5 cm distance. However, the thickness of this shielding grid was 1 mm in comparison to our foil with the thickness of 10 µm. The study also stated that any shielding accessory, even when correctly applied, may attenuate not only man-made polarized EMFs, but also the natural non-polarized EMFs responsible for the biological rhythmicity and well-being. Shielding accessory, we used in this study had shielding range starting from 10 MHz comparing to e.g. Schumann resonance which lies approximately within the range of 7.8 – 45 Hz. According to Palanisamy et al. [29], the surface resistivity can be used to predict the EM shielding ability of the fabric samples. The study informed that aluminium foils had a very good shielding ability. Our results also showed that the attenuation effectiveness of ALF was comparable to AGV, but still AGC performed better for all frequencies.

According to the basic information, the protective caps should be suitable to attenuate 60 - 80 dB within the range of 10 MHz - 3 GHz. However, the observed effect was much lower, on average by 6 - 16 dB. It is possible, that the difference could be caused by the real conditions of the measurement setup. In our study, protective accessories were used to obtain attenuation in the human tissue. In general, attenuation occurs when the EM waves pass through the material either by a wave absorption or a diffraction in the case of inhomogeneous materials. The properties of the biological tissue affect the amount of energy absorbed, which is related to the depth of the penetration. The study by Buckus et al. [30] informed that the highest intensity of the electric field generated by the mobile phones is distributed through the ear canal and the intensity of the electric field (900 MHz, 1800 MHz, 2100 MHz) decreased exponentially from the periphery to the center of the head. Research group Safarova et al. [31] stated, that EM shielding depends on the fabric material. Mainly the fabrics embedded with the metal fibres (also known as the metal hybrid fabrics) can increase the effectiveness of EM shielding what could be tailored by modifying the metal content, grid size and the fibres geometry. According to the study [32], the absorption of EMF depends mainly on the number of the layers rather than the thickness of the shielding material. The closer the layer is to EMF source the higher is the absorption performance while the layer further from the exposure shows primarily attenuation caused by an internal reflection. Research by Jakubas et al. [33] investigated, that the two-layer composite consisting of the mixture of the iron scale and the nanocrystalline powder with construction polymer, had the overall shielding effectiveness of 75 dB within the range 0.5 - 2 mm of the shielding material. Compared to our AGC and AGV the attenuation value was approximately 7 times smaller (11 dB). According to the other study [34], the shielding effectiveness increased with the number of aluminium layers where the optimal number of the layers was 4-5. Our protective caps (AGC, AGV, ALF) contained only 1 shielding layer, what may explain the lower EMF attenuation.

The limitation of this study was the positioning system holding the antenna. In the future studies, the positioning arm, which would better copy the shape of the phantom, would be necessary. It will be also interesting to expand the measurements to 4G or 5G frequency bands and also the extremely low frequency bands (e.g. Schumann resonance).

Conclusion

In our study we focused on the textile accessories and their ability to attenuate RF EMF. According to the results, the best shielding provided the protective cap containing silver. The highest effectiveness of this cap was confirmed for each frequency. An aluminium foil as a temporary cap revealed good shielding properties compared to the classic caps, which did not provide any attenuation. We proofed that it is necessary to pay an attention to the material composition from which the protective accessory is made of. But, important is also the shape where the classic cap revealed higher attenuation properties compared to the visor type cap. We conclude, that the protective accessories are able to reduce EMF and the possible detrimental EMF effects thus protecting the health, especially of the persons suffering from electromagnetic hypersensitivity.

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